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Technical Report

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MANUFACTURING METHODS AND TECHNOLOGY

AUTOMATIC DEBURRING

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This report summarizes the results obtained in the use of multi-axis programmable robots to deburr gas turbine engine components. A description of the equipment used, deburring techniques, and off-line programming methods are included. A number of production parts were deburred using the systems developed.

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PREFACE

This final technical report covers work performed under MM&T Contract DAAE07-83-C-R077 (Automatic Deburring) from June 1983 to December 1987. The contract is sponsored by the U.S. Army Tank-Automotive Command, Warren, Michigan. Contract administration is under technical direction of John W. Herbert, Army project manager. The Textron Lycoming program manager is Ronald A. Hirsch.

The Automatic Deburring Project was funded in two phases. Each phase was supported by separate subcontractors as follows:

Phase I: E.S-I, Albany, N.Y.
Phase II: American Technologies, Allendale N.J.

In addition, internal support was provided by Lycoming's Advanced Manufacturing Technology Laboratory and Numerical Control Programming personnel, whom we wish to thank for their contributions to this project. They are:

Franklin Blackwell	N.C. Programmer
Jeffrey Gorman	Programmer Analyst
William Janus	Lab Supervisor
Robert Martire	CIM Engineer
Robert Nicholson	N.C. Programmer
Charles E. Turner Jr.	Lead Technician

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1.0. INTRODUCTION

This final technical report, prepared by Textron Lycoming for the U.S. Army Tank-Automotive Command under Manufacturing Methods & Technology contract DAAE07-83-C-R077, describes Phase I and II of a program to apply automatic deburring to AGT-1500 engine components. The elimination of burrs produced during machining operations in the production of gas turbine engines is a costly and time-consuming process. The use of robotic deburring as a replacement for hand deburring represents an opportunity to lower costs and improve quality, while eliminating a tedious and hazardous task.

The technology necessary to perform this work was developed by Textron as an extension of techniques used in industry to deburr a variety of commercial parts.

2.0. OBJECTIVE

The objectives of this Manufacturing Methods & Technology-funded project were to: investigate currently available deburring technologies; perform programming and deburring trials on 12 selected AGT-1500 components manufactured at Lycoming and recommend other deburring technology where the design of the component prohibits burr removal by robot; develop off-line programming and integrate it into the system; design fixtures for the 12 components; build fixtures for the air diffuser, forward header, and rear header; develop quality control criteria; provide a detailed cost analysis; collect data toward the development of the unit; develop an implementation plan; and prepare a final report.

3.0. CONCLUSIONS

Automatic (robotic) deburring can be implemented into production and provide substantial cost savings and quality improvements. The use of spring-loaded toolholders and carbide rotary files were found to be the best way to achieve uniformly deburred edges. The ASEA IRB L6/2 robot had faster response time, more rigidity and better maneuverability than the ASEA IRB 60/2 robot and is therefore more suitable for deburring applications of this type. A servo-controlled two-axis positioner used in conjunction with the robot is required to provide programming ease and deburring uniformity. Off-line programming shows promise of being able to provide programs which would require some 'touchup' on line but would nevertheless, improve the productivity of the system.

4.0. RECOMMENDATIONS

Enhancements to the Phase I and Phase II systems are required to allow for transition into production. The Phase I system must be mounted on the base/positioner which has been purchased. The sixth axis should be

removed and the toolholder mounted on the fifth axis flange. Both systems must be equipped with tool exchangers, safety mats and fencing to allow safe operation in a production environment. Additional work on off-line programming of a five-axis system should be pursued. Inherent problems with the Tool Center Point (TCP) definition which are present in the ASEA IRB 60/2 six axis system makes off-line programming impractical on this system. The Phase I and Phase II systems, when modified, will both be five-axis robotic systems. Without the sixth axis, the TCP definition problems we uncovered are alleviated. This will make off-line programming a viable alternative again. Our recommendation is that another attempt at off-line programming be made once the systems are implemented into production. Trial deburring of other AGT-1500 parts should continue as allowed by the production schedule.

5.0. DISCUSSION

5.1. Background

5.1.1. Phase I. The project started in June 1983 with the award of Phase I funding. A specification for a robotic deburring system was written and submitted to vendors for quotation. E.S-I of Albany, N.Y. was selected to provide the system based on similar work the company was in the process of doing for the Watervliet Arsenal.

The system was delivered in December 1985 and consisted of an ASEA IRB 60/2 industrial robot, an E.S-I-designed and -built indexing turntable, and an E.S-I numerically controlled end effector. The end effector was programmable for different tool speeds and was equipped with a quill feed and force sensors for detecting tool pressure against a part edge.

Problems plagued both the reliability of the E.S-I-designed equipment and the results obtained with their use. Lack of compliance in the end effector produced chamfers of one-eighth inch to one-half inch on parts where a break edge was called for on the drawing. E.S-I was given ample opportunity to demonstrate the ability of their system to perform to specification and failed in this effort. While E.S-I was involved in the program, not a single edge was successfully deburred.

5.1.2. Phase II. Placement of the Phase II equipment order took place in July 1986. At this time, E.S-I was in the process of attempting to make their system perform to specification. It was decided to begin a parallel effort, using a second subcontractor to help achieve positive results. A second robot, an ASEA IRB L6/2, was purchased and along with an Aronson two-axis positioner was mounted to a common structural steel base. The second subcontractor was American Technologies of Allendale, New Jersey.

Since this robot/positioner combination was better suited to successfully achieve the project's goals, it was decided to program this

system to deburr the three major components under consideration: the air diffuser P/N 3-130-010-36; forward header P/N 3-500-261-06; and rear header P/N 3-500-262-08. Programming was done by American Technologies personnel under the direction of the Textron project manager at A.T.'s New Jersey facility.

Concurrently, changes were made to the Phase I system located at Lycoming to improve its capability. As a result of the changes made, the system was programmed to deburr nine AGT-1500 components to demonstrate the feasibility of performing robotic deburring on these components. The components are shown in Table 5-1. Varying degrees of success were achieved in deburring these 12 components, as discussed in this report.

5.2. System Configuration

5.2.1 Phase I System. As originally purchased and configured by E.S-I, the system consisted of an ASEA IRB 60/2 six-axis industrial robot, an indexing turntable and a numerically controlled spindle both designed and built by E.S-I. The turntable and spindle were controlled by an Allen Bradley PLC connected to the robot controller via input-output (I/O) interface. The robot and turntable were installed in the Advanced Manufacturing Technology Laboratory, where they were lagged to the floor per a layout supplied by E.S-I.

Tooling for this system consisted of carbide burs, Cogsdill hole deburring tools, and various brushes (steel) which were mounted in the spindle. The spindle was equipped with a force sensor to enable the system to decrease or increase feed rate as the tool deburred an edge depending on the burr size (force variation) detected by the sensor. Since the toolholder had no compliance to accommodate edge location variation, it was also thought that the force sensor could be used to detect edges to provide a starting point for the programs. This end effector configuration was later abandoned in favor of the ASEA spring-loaded dual toolholder, as shown in Figure 5-1.

Fixtures for the nine parts programmed using this system were built in the Advanced Manufacturing Technology Laboratory at Textron Lycoming.

5.2.2. Phase II System. This system, shown in Figure 5-2, consists of an ASEA IRB L6/2 five-axis industrial robot, a two-axis Aronson servo-controlled positioner and a structural steel base on which the robot and positioner are mounted. The positioner is driven by two ASEA servomotors and is controlled by the ASEA S2 controller. This system was constructed by American Technologies.

Tooling for this system consisted of an ASEA spring-loaded dual toolholder, ARO air motors, and an assortment of carbide rotary files and Tynex nylon brushes. The toolholder is designed to accommodate one

Table 5-1. Parts Designated for Feasibility Study

Part Number	Description
3-130-940-01	Housing, No. 4 Bearing
3-140-001-24	Housing, Power Turbine
3-140-291-18	Enclosure, Power Turbine Aft
3-140-144-20	Shroud, Outer
3-100-400-02	Shroud Set, Outer Inlet Guide Vane
3-020-176-12	Cover, Bearing Support
3-140-037-10SF1	Gear Ring, 1st Stage
3-110-051-17	Nozzle Assy, 2nd Stage
3-020-590-04	Ring Gear Assy

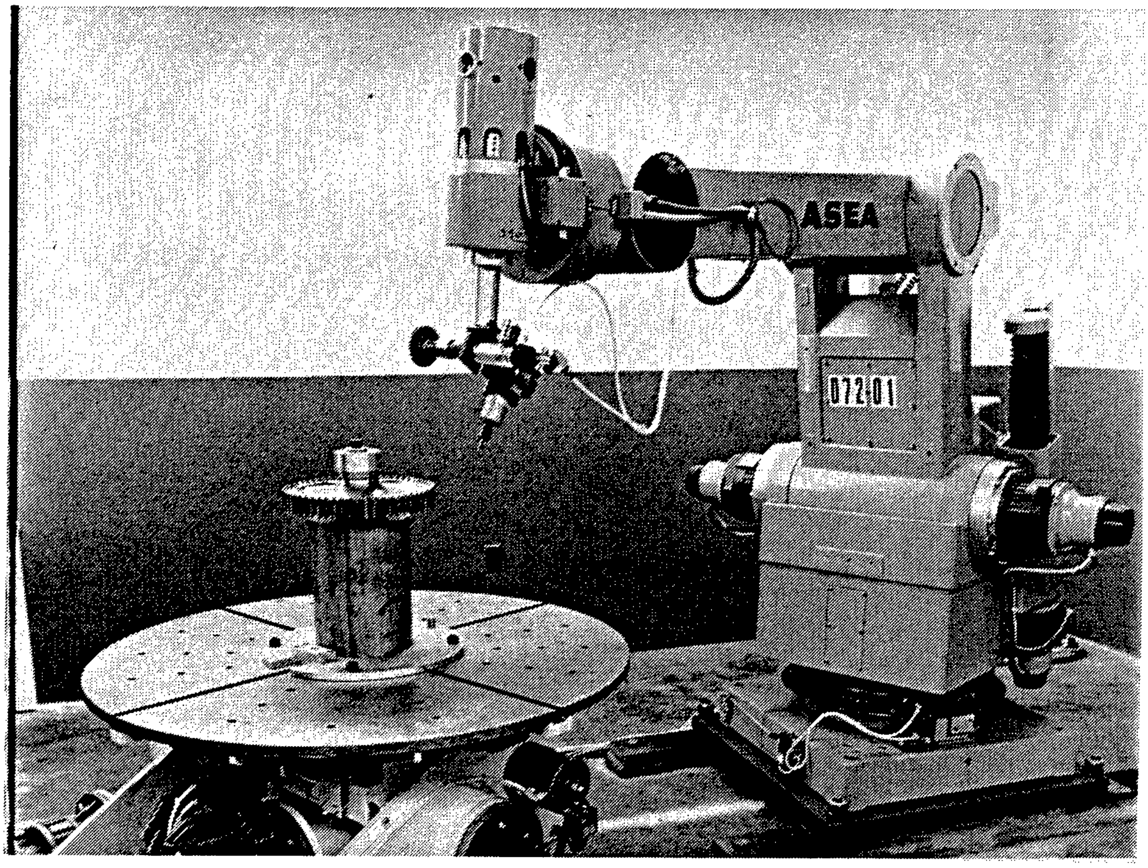


Figure 5-1. Phase I System

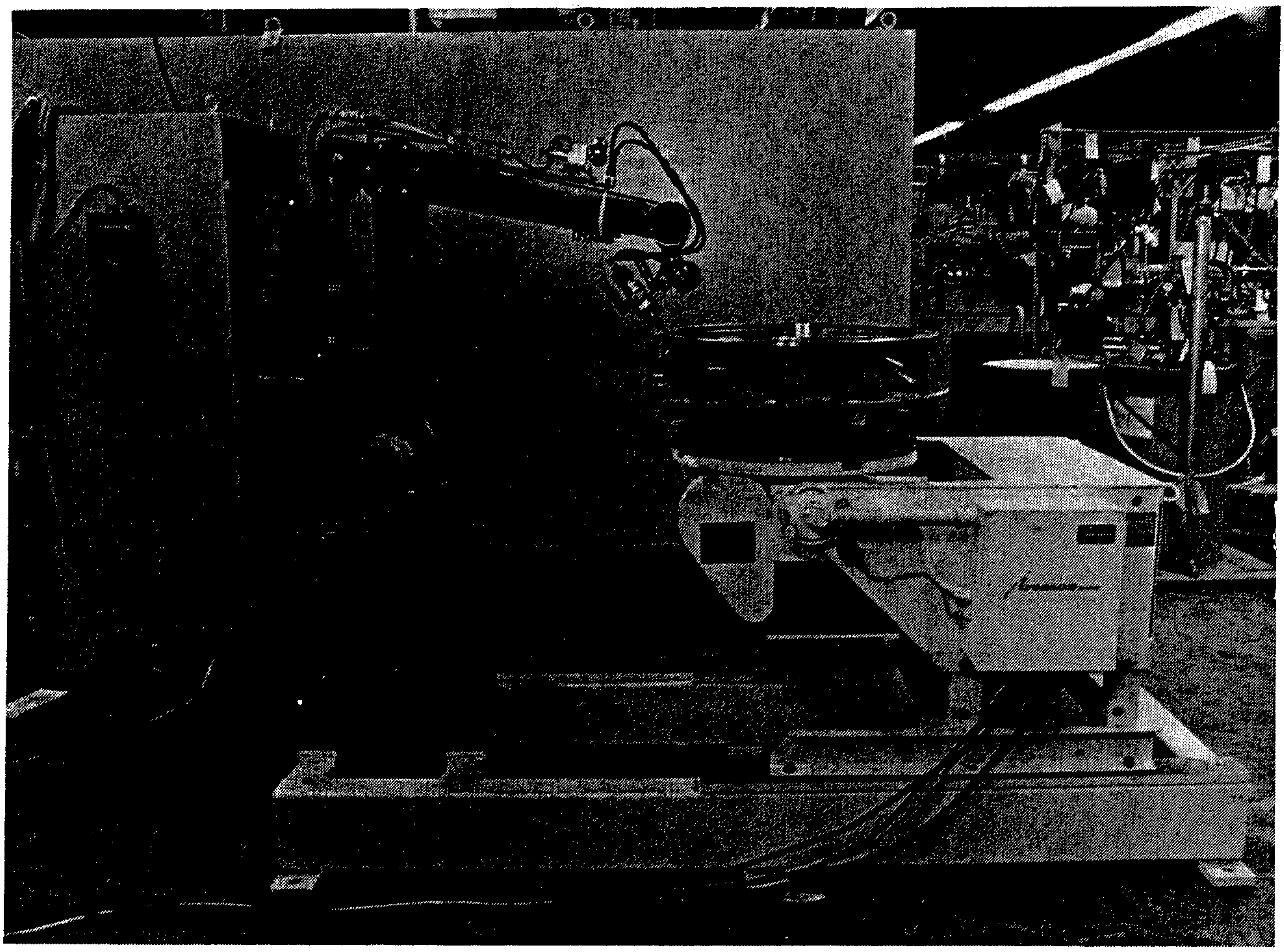


Figure 5-2. Phase II System

air motor in a bidirectionally spring-loaded holder and another in a rigid mount. The motor in the spring-loaded mount was equipped with carbide rotary files to suit the part being deburred while the fixed motor was used with a Tynex brush or Cogsdill hole deburring tool.

Fixtures used with this system were built by subcontractors and modified by American Technologies to allow mounting on the Aronson positioner.

5.3. Programming and Trial Deburring

Programming techniques were developed which allowed smooth tangential initial contact to the work piece which is critical to achieving a uniform edge. Tool pressure was gradually relieved near the end of a cut to eliminate 'tool snap' as the spring-loaded tool left the work. Robot speeds were adjusted to create deburring programs which had smooth, uniform feed rates along complex contours.

5.3.1. Phase I System. Programming for the Phase I system in its original configuration (Figure 5-3), was done by E.S-I personnel on P/N 3-130-010-36 air diffuser, initially at their Albany facility and later at Lycoming's Advanced Manufacturing Laboratory. Results of trial runs were unacceptable. Material removed ranged from 1/8-inch to 1/2-inch chamfers. Attempts to use the force sensor to locate the edge to be deburred were unsuccessful. The Phase I system was initially equipped with a indexing rotary-tilt positioner which made programming extremely tedious. Parts which contained repetitive details required programming of a 45-degree segment of these details. The program could be repeated only after indexing the positioner 45 degrees. Creating a program for a complex detail, such as a gear tooth for example, required 15 to 30 minutes, and with this system, had to be done for each tooth in a 45-degree segment. Since E.S-I had a contractual obligation to provide a turnkey system capable of producing a deburred edge per Lycoming's specification sheets, they were given many opportunities to produce acceptable results. In October 1986, E.S-I abandoned the project after a dispute with Textron management concerning payment for an ASEA serviceman.

The system was modified to conform to an industrially proven configuration for application to the required parts. Programming was resumed, with the work being done by Textron Lycoming personnel from the Numerical Control Programming group. Figures 5-4, 5-5, 5-6, 5-7, and 5-8 show representative deburring operations. This work, which was done on the nine AGT-1500 components listed in Table 5-1, demonstrated the feasibility of deburring specific edges of these components.

5.3.2. Phase II System. Programming for the Phase II system was accomplished by American Technologies personnel. Programs were developed for the air diffuser P/N 3-130-010-36, forward header P/N 3-500-261-06, and rear header P/N 3-500-262-08. Trial runs produced parts with

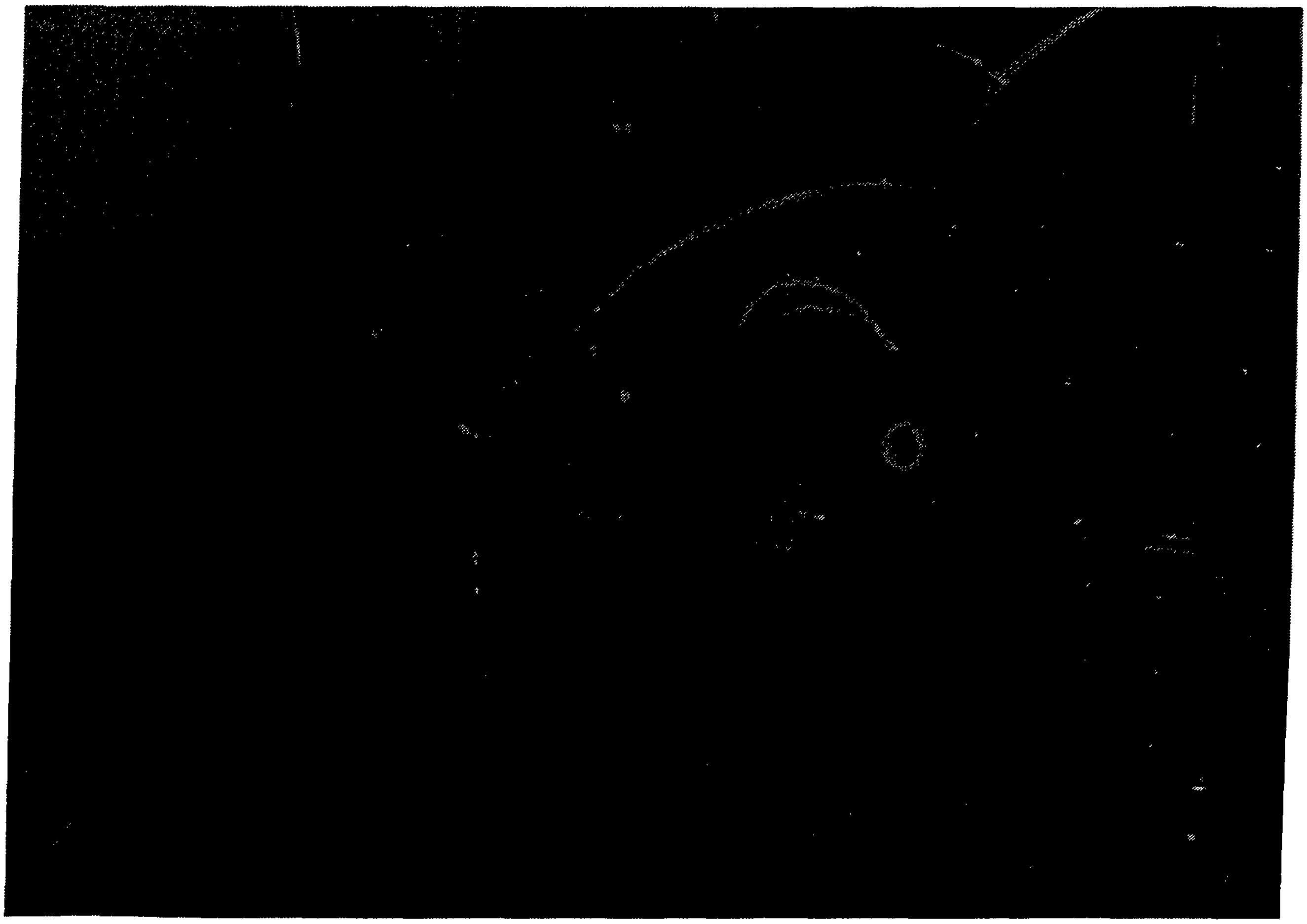


Figure 5-3. Phase I System, Original Configuration

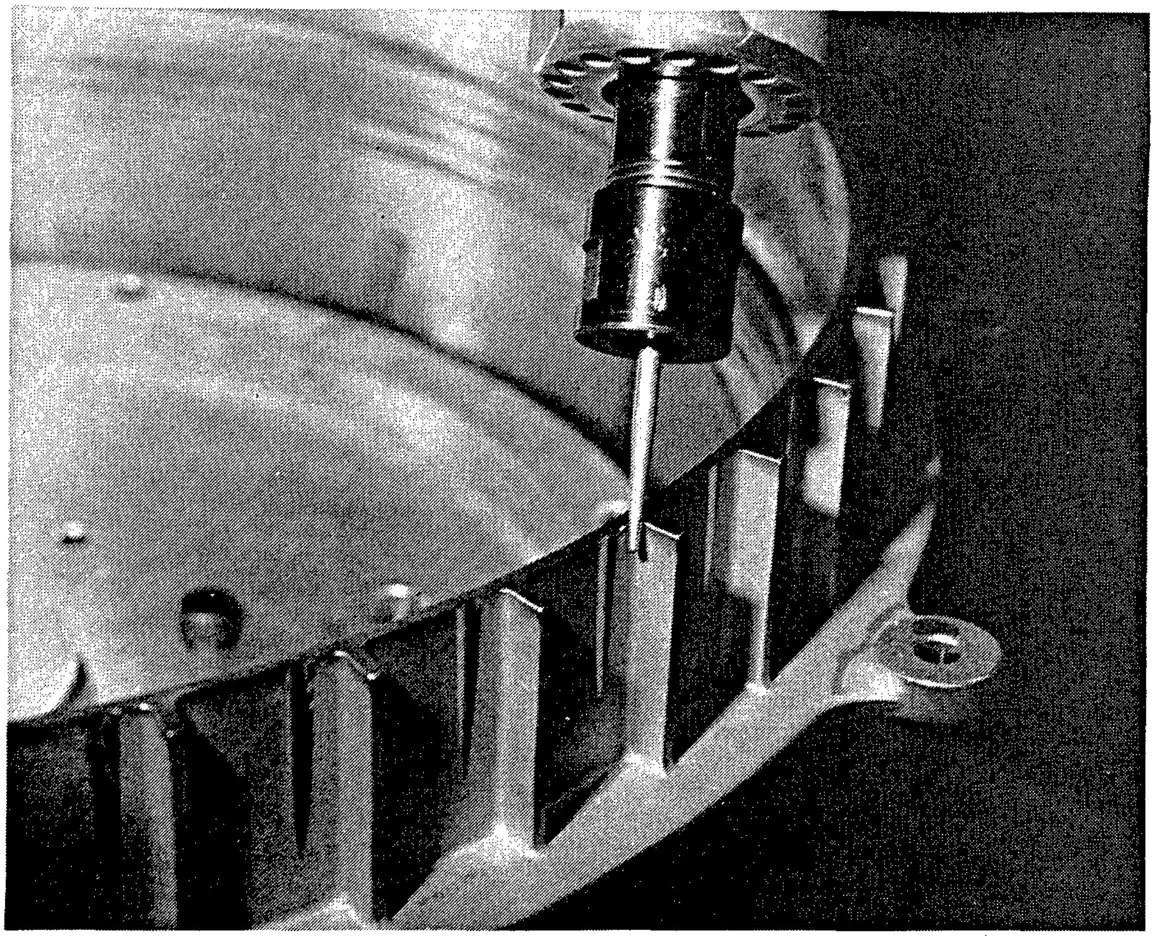


Figure 5-4. Deburring P/N 3-140-144-20, Outer Shroud

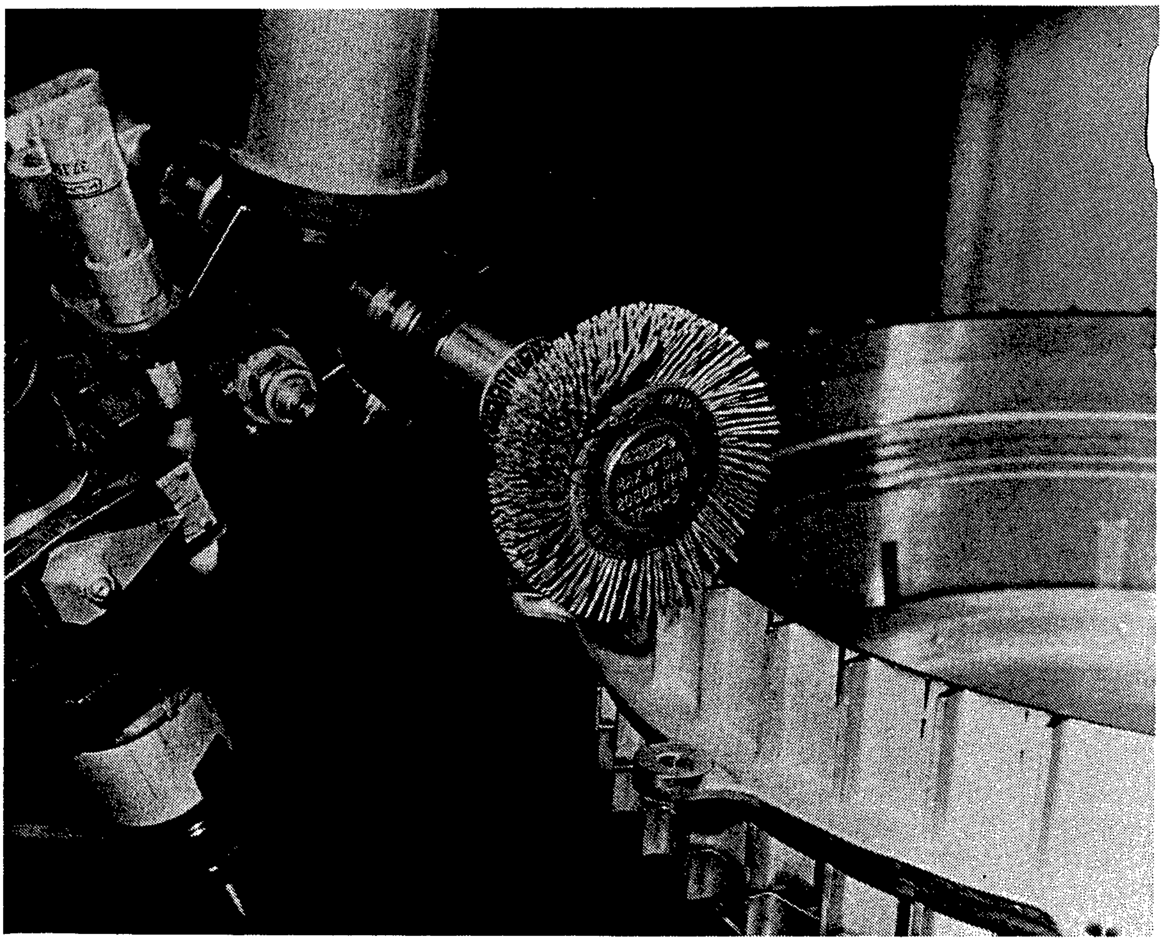


Figure 5-5. Removal of Secondary Burrs, Outer Shroud

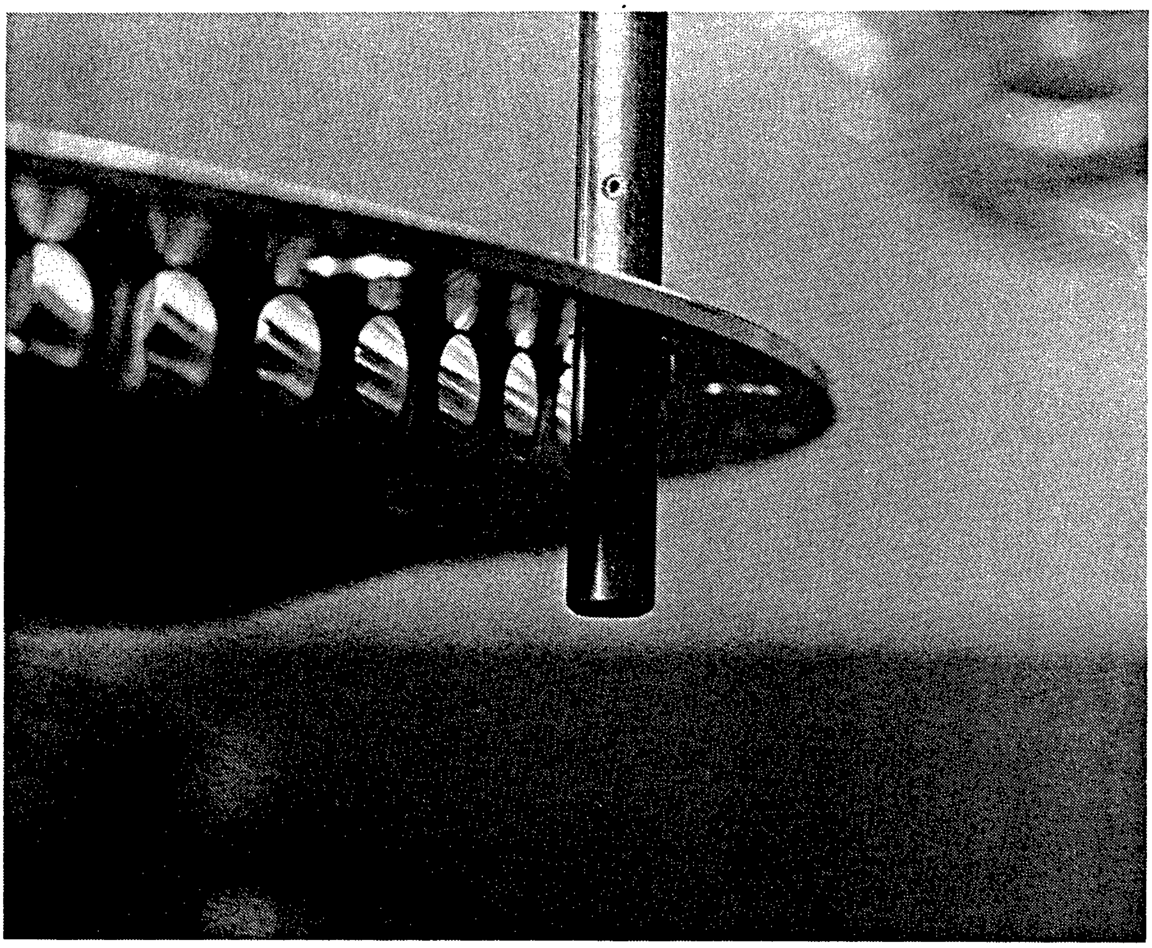


Figure 5-6. Hole deburring, Number 4 Bearing Housing

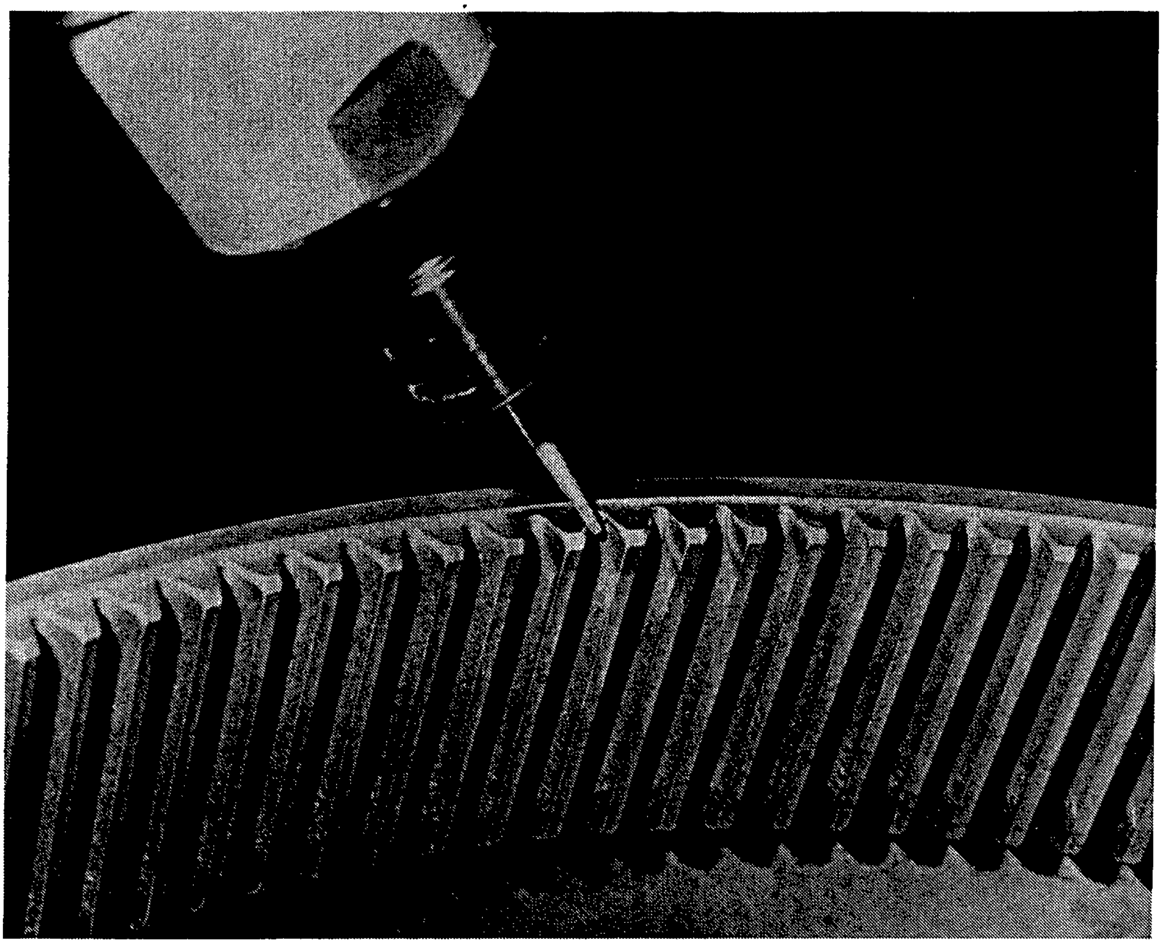


Figure 5-7. Gear Tooth Deburring, Ring Gear Assembly

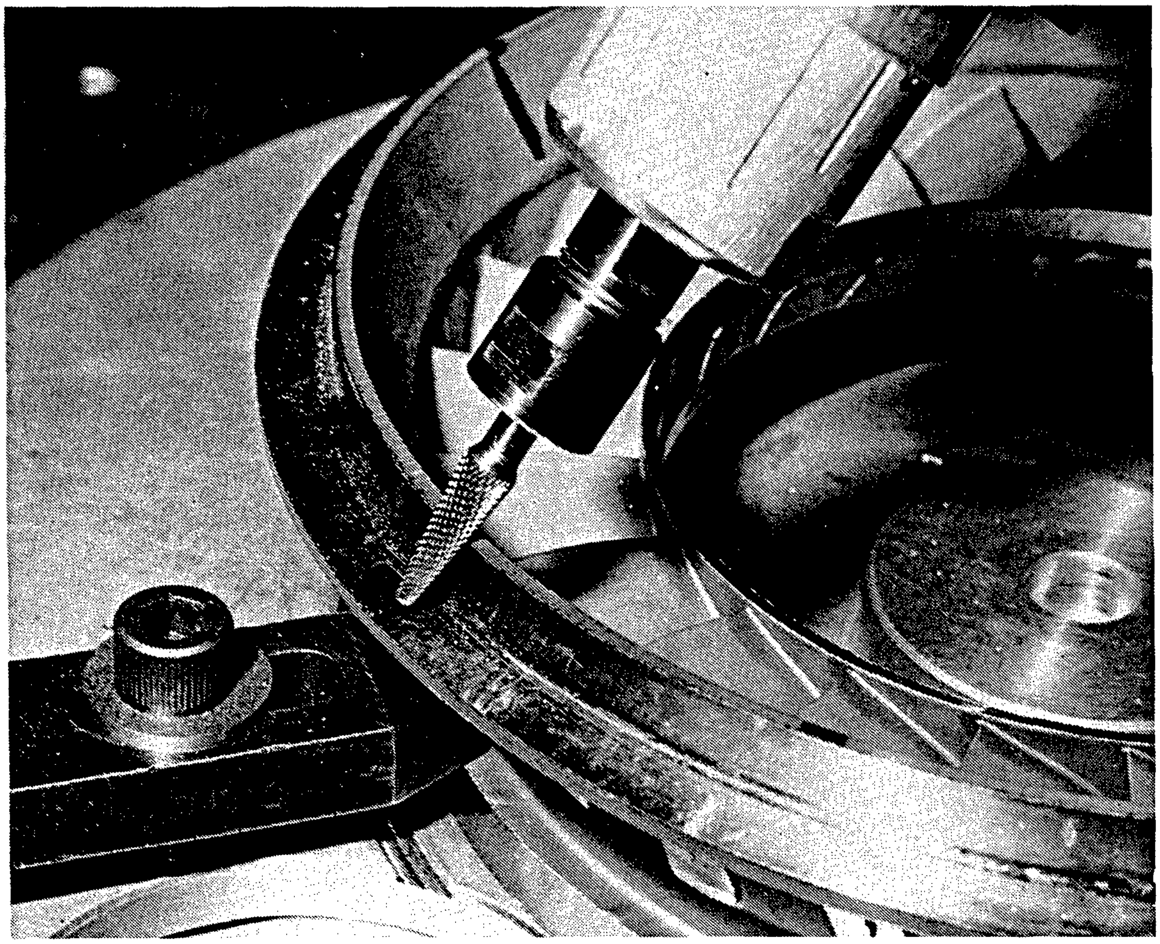


Figure 5-8. Deburring Outer Edge, Second Stage Nozzle Assembly

deburred edges which were of acceptable quality as shown in Figures 5-9, 5-10, and 5-11.

Parts were cut with a variety of rotary carbide files. Initial trials using a diamond-dust-impregnated cutting tool proved unsatisfactory since tool wear occurred rapidly on the stainless steel cast edges.

This system proved to have many advantages over the Phase I system. The positioning table associated with this system consists of two servo-controlled axes, rotary and tilt. Control of the table motion was programmable through the teach pendant of the ASEA S2 controller. Creating programs for repetitive details was much more efficient, and once the program had been created for one tooth on a gear, for example, the part was indexed one tooth and the program was repeated as many times as required. The planned modification of the Phase I system allows this procedure.

The type of robot used with the Phase II system also was a distinct improvement over the Phase I robot. The ASEA IRB L6/2 robot (Phase II) provided smooth motion and prompt servo response, characteristics which are necessary for high-speed contouring and cornering. Experience with the Phase II system resulted in a plan to improve performance of the Phase I system. The plan involved design and construction of a steel base on which the ASEA IRB 60/2 robot would be mounted along with an Aronson servo-controlled, two-axis positioner. The base/positioner was ordered from American Technologies and delivered to Lycoming for integration with the ASEA IRB 60/2 robot.

5.3.3. Results of Deburring Trial Runs. Table 5-2 is a summary of the results which were obtained during actual deburring trial runs. The results are described in the following paragraphs.

Part number 3-130-010-36, air diffuser, requires two deburring operations, Op. No. 131 and Op. No. 141. We were able to deburr all of the edges called out in these operations which we could physically reach with the robot. The interior of the air diffuser was less successfully deburred due to this limitation. Approximately 90% of the required work called out in operation 141 and 50% called out in 131 was performed.

Part number 3-500-261-06, forward header, requires operations 134 and 138. Because of relatively good access to the edges of this part we were able to perform 85% of the operations, including all of the outer edges of the 'footballs and triangles.'

Part number 3-500-262-08, rear header, requires operations 97 and 101. This part also allowed access to 85% of the edges which required deburring. The rear header and the two above parts are produced on Lycoming's Flex Line. The Phase II system will be installed in this area and will be used in production to deburr these parts.

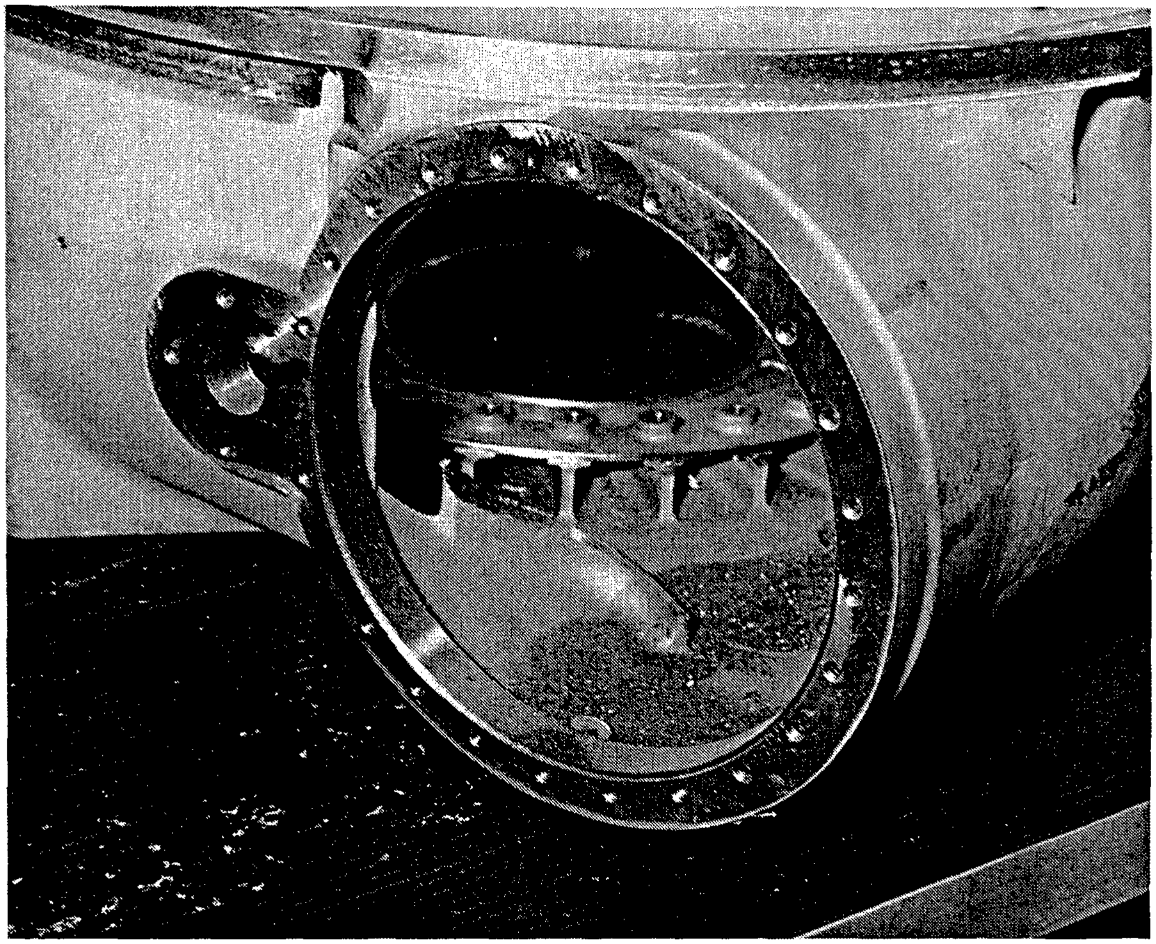


Figure 5-9. P/N 3-130-010-36, Air Diffuser After Deburring 'Horn'

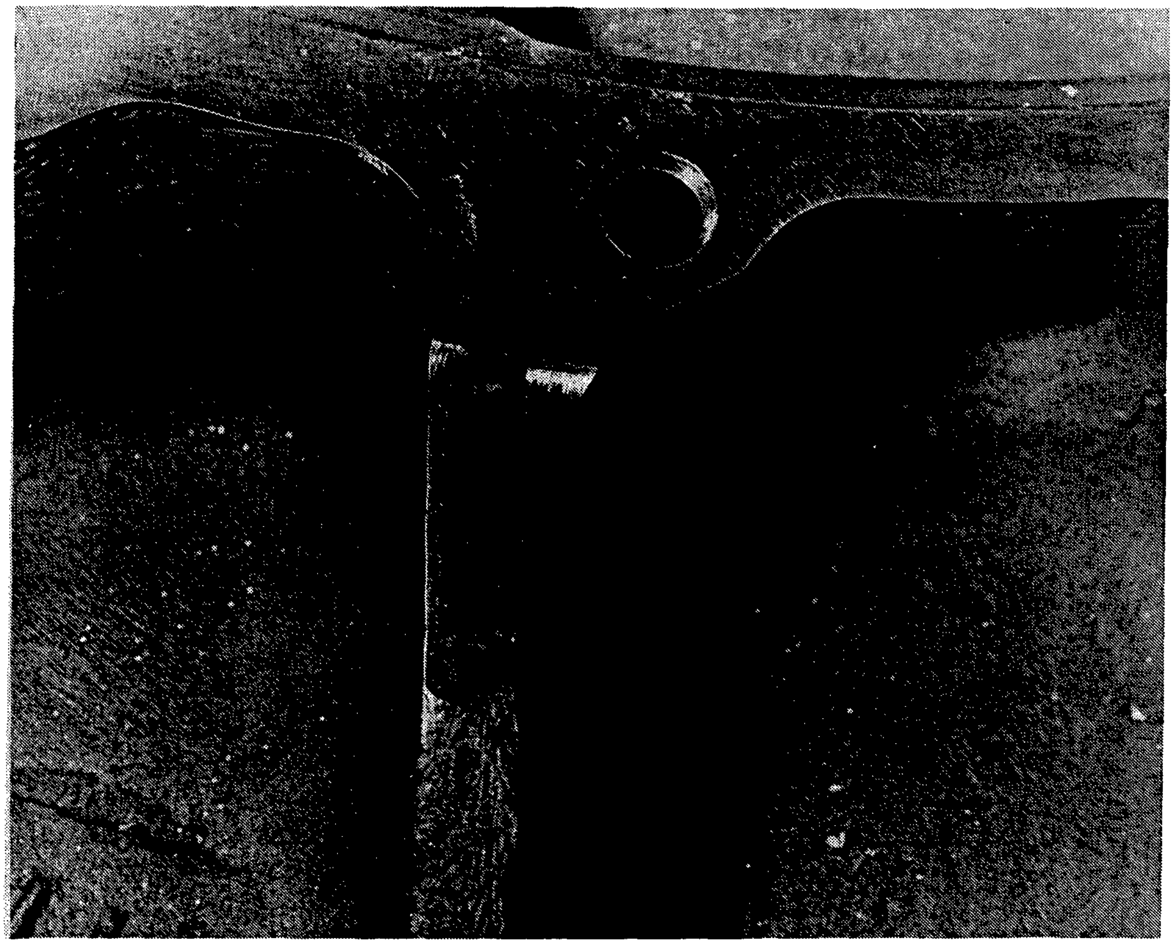


Figure 5-10. P/N 3-500-262-08, Rear Header After Deburring

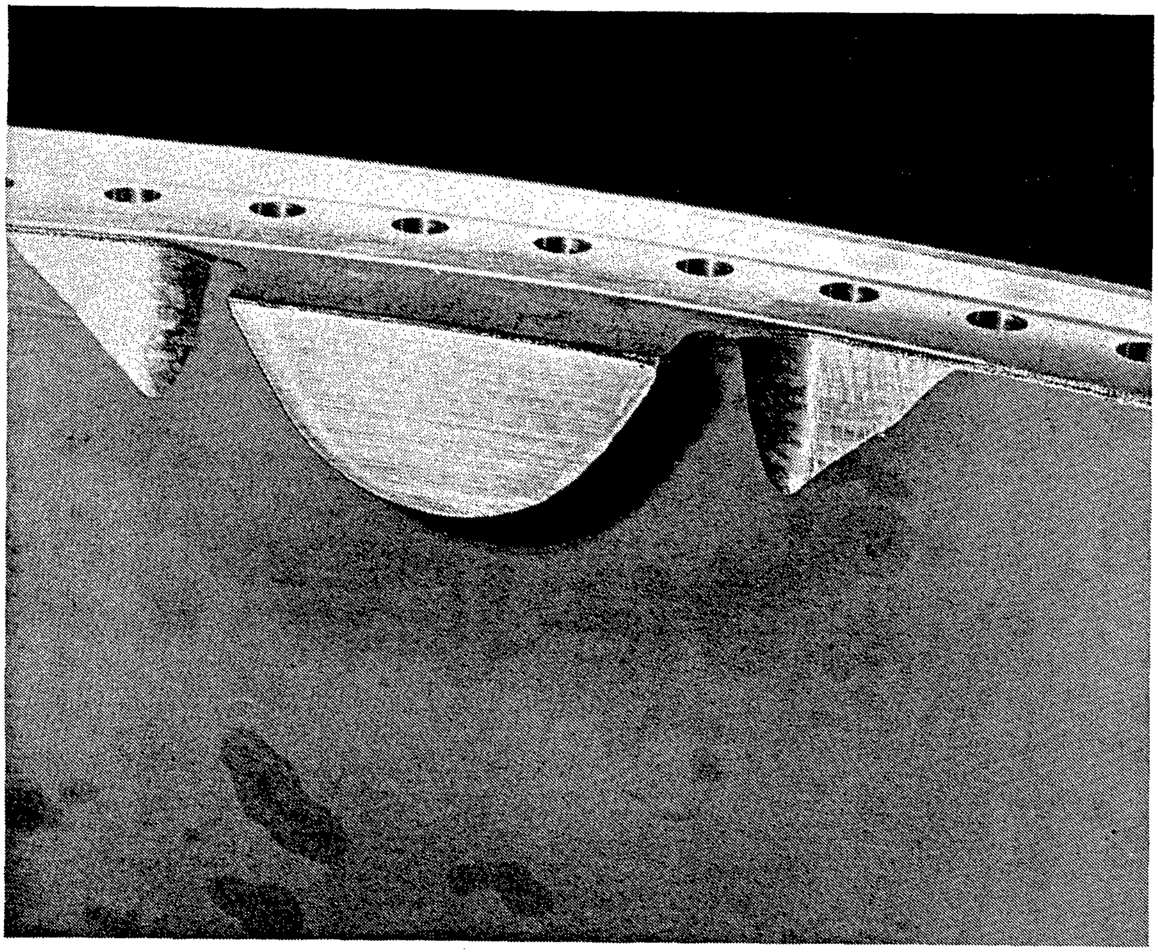


Figure 5-11. P/N 3-130-010-36, Air Diffuser After Deburring

Table 5-2. Results of Deburring Trial Runs

Part Number	Operation No.	Results
3-130-010-36	131	50% of edges shown
	141	90% of edges shown
3-500-261-06	134	85% of edges shown
	138	Outer edges, footballs & triangles
3-500-262-08	97	85% of edges shown
	101	85% of edges shown
3-130-940-01	380	Holes in flange, circumferential edges
	440	Outer circumferential edges
3-140-001-24	233	Outer circumferential edges
	492	Outer circumferential edges, holes
3-140-291-18	80	Circumferential edges
3-140-144-20	106	Surfaces B, C, D, & E
	225	Outer edges
3-100-400-02	232	Complete operation
	282	Holes, slots
3-020-176-12	93	I.D. and O.D. edges
	131	Flange holes
3-140-037-10SF1	121	Top land edges, outer end of gear tooth
	150	Cannot be done
3-110-051-17	30	Inconel, results unsatisfactory
3-020-590-04	250	Outer edge of gear tooth, top land edges except inner edge of gear tooth

Part number 3-130-940-01, number 4 bearing housing, calls for deburring Op. No. 380 and 440. We were able to deburr all of the flange holes and the circumferential edges. The operations call for other work which we cannot reach with the robot. This part and all of the following parts were deburred using the Phase I system, in order to demonstrate the feasibility of deburring these parts.

Part number 3-140-001-24, power turbine housing, requires operations 233 and 492. Again, due to physical constraints, we were only able to deburr the outer circumferential edges and holes. This is an Inconel part. The nature of this material is such that rotary files produce poor edge quality.

Part number 3-140-291-18, aft power turbine enclosure. Two circumferential edges called out in Op. No. 80 were deburred. Other edges could not be reached.

Part number 3-140-144-20, outer shroud. Edges of surfaces B, C, D, and E, of operation number 106 and the outer edges of operation 225 were deburred successfully. Other surfaces called out in these operation were not accessible.

Part number 3-100-400-02, outer inlet guide vane shroud set requires operations 232 and 282. We were able to do operation 232 completely, and the holes and slots called out in operation 282.

Part number 3-020-176-12, bearing support cover calls for operations 93 and 131. The I.D. and O.D. edges specified in Op. No. 93 and the flange holes called out in Op. No. 131 were deburred.

Part number 3-140-037-10SF1, ring gear, requires operations 121 and 150. We were able to deburr the top land edges of the gear teeth and around the outer end edges of the teeth, but the inner ends of the gear teeth were not accessible. Operation 150 also could not be done due to poor accessibility.

Part number 3-110-051-17, the second stage nozzle assembly is an Inconel part. As with the other Inconel part which we deburred, edge quality after deburring was poor. We were unable to obtain satisfactory results.

Part number 3-020-590-04, ring gear assembly calls for operation 250. We were able to deburr the outer edges of the gear teeth and the top lands. The inner edges of the teeth are not accessible.

5.4. Tooling

The spring-loaded toolholder used was an ASEA design which evolved as a solution to three problems associated with successful robotic deburring: variation in location of the part being deburred in the holding fixture; variation in part size (manufacturing tolerances); and burr size variation. The toolholder is sprung in only one direction and the tool

was positioned so that tool compliance was in a plane perpendicular to the edge being deburred. Spring force could be adjusted by varying the preload on the spring. The optimal spring force has been found to be 3 to 4 Newtons. The toolholder is rigid in the direction normal to the plane of compliance which minimizes vibration during the deburring operation. System stiffness in the direction of tool feed was also found to influence vibration. The IRB L6/2 robot is significantly more rigid and less prone to vibration or tool chatter than the IRB 60/2 robot.

The selection of ARO air motors over electric motors was made since they are well suited to the application, and Lycoming uses them exclusively for manual deburring. In addition, Lycoming has an in-house rebuild facility for them. Air tubing to the motors had to be carefully arranged to avoid disturbing the toolholder's free motion.

An assortment of carbide rotary files (Figure 5-12) was obtained to provide a selection of tools for various part configurations. In addition, diamond-dust-impregnated tools (Figure 5-13) were tried with unsatisfactory results. Files with fine tooth patterns produced better results than those with coarse patterns. Small secondary burrs were present after burr removal with the rotary file. These were removed by means of a carbide-impregnated nylon filament brush (Figure 5-14). In addition, an assortment of various size Cogsdill tools (Figure 5-15), were obtained for hole deburring.

5.5. Cutting Method

Cutting was performed in the climb cutting mode which was found to produce the least vibration. Cutting speeds were 1,500 to 3,000 surface feet per minute for the carbide rotary files, while brushing was done at 4,000 to 5,000 surface feet per minute. Tool feed rates were in the range of 3 to 10 feet per minute. Hole deburring was done with the Cogsdill tools in a 600 r/min air motor. Tool deflection normal to the surface allows for variation in part edge location and burr size while maintaining adequate cutting force on the part. It was found that large burr size variations did not affect the size break edge produced.

5.6. Off-Line Programming

5.6.1. System Configuration. Off-line programming was pursued as part of the Automatic Deburring Project. The system configuration required for this task consisted of a computer-aided design/computer-aided manufacturing system (CAD/CAM) for modeling the robotic cell and the part to be deburred, a post processor to convert the graphical representation of the deburring task into the proper format for processing through the actual off-line programming system software, and an IBM PC where the off-line programming system resides and processes the post processed data into the actual robot control machine language format. The IBM PC

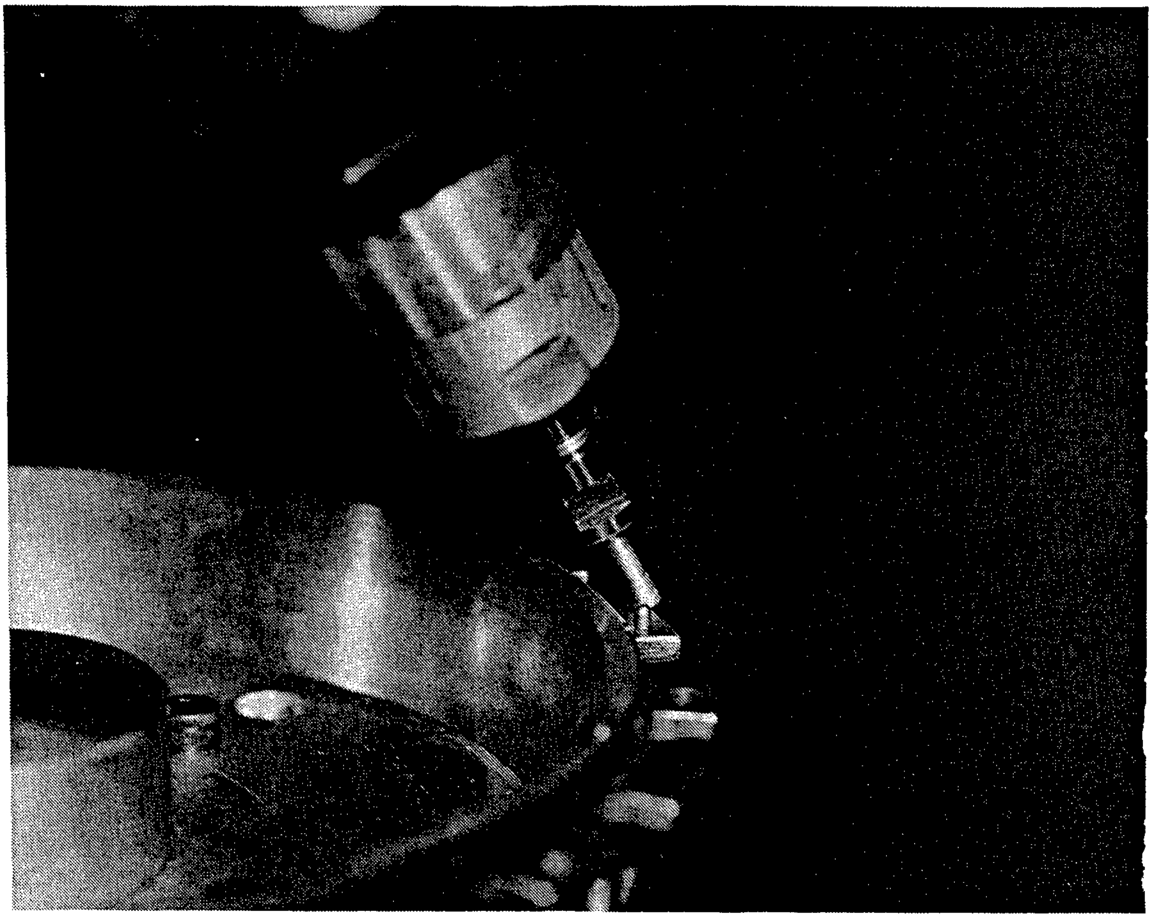


Figure 5-12. ASEA Toolholder and Carbide Rotary File

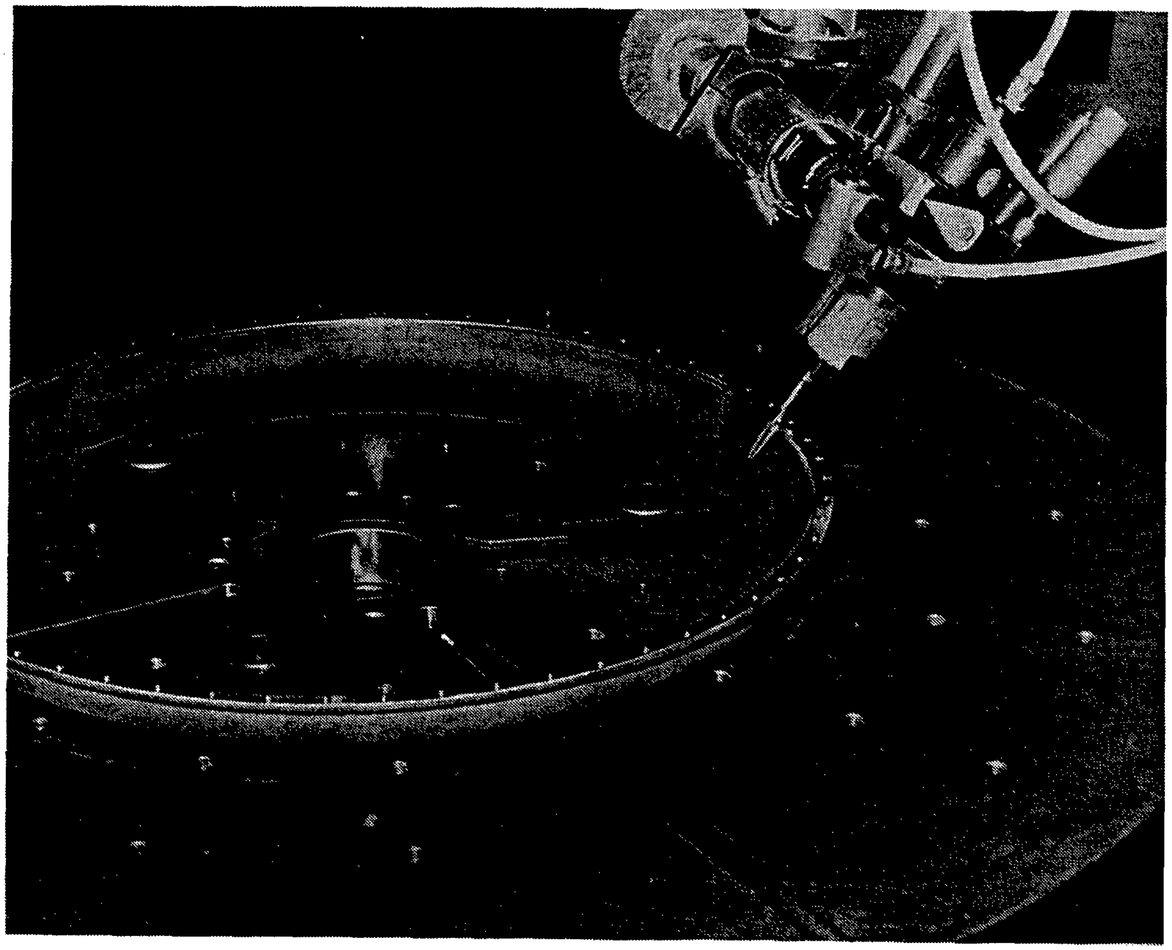


Figure 5-13. P/N 3-100-400-02, Shroud Set

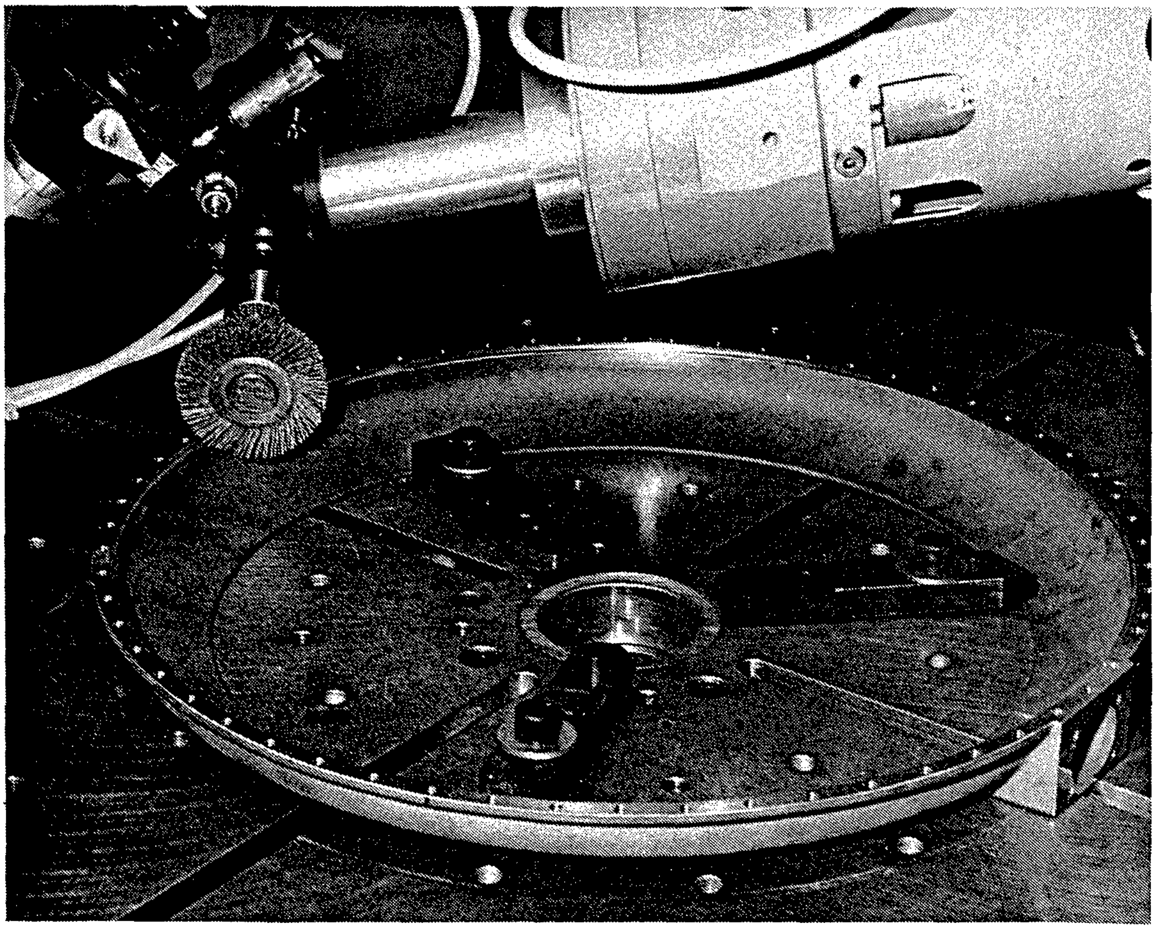


Figure 5-14. Application of Nylon Brush to Power Turbine Aft Enclosure

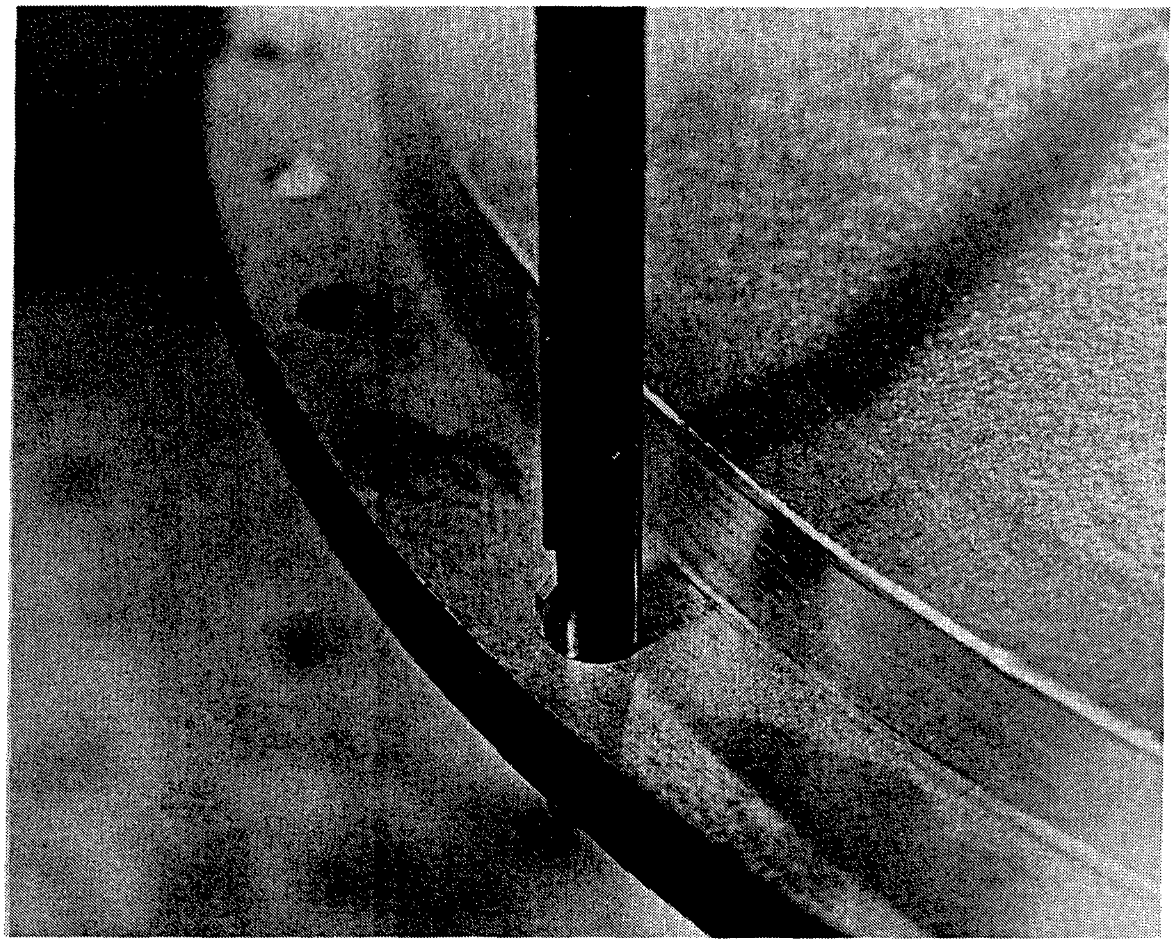


Figure 5-15. Hole Deburring with Cogsdill Tool

also serves as a file transfer device between the mainframe computer and the robot controller.

Various CAD/CAM Systems were evaluated for this application. They were: CADAM Incs.' "CADAM"; Dassault Systems' "CATIA"; and Mc Auto Systems' "Unigraphics."

The system selected was CATIA. It is fully compatible with our IBM mainframe computer and is capable of generating a solid model for full three-dimensional display and manipulation. Dassault Systems U.S.A. was contracted to develop the post processor that would convert the graphic representation of the deburring task into a format acceptable to process through the ASEA off-line programming software package called "OLP" (Off Line Programming) which resides on the IBM PC. The actual procedure that was used to generate an off-line deburring program is described in the next three paragraphs.

The robot and all associated tooling were drawn to scale and positioned in the graphics system exactly as on the shop floor, as shown in Figure 5-16. Next the part was drawn to scale and it was positioned both radially and axially in the graphics system.

Through the use of system function keys and menu options, the simulated robot was then guided through a series of motion commands which position the deburring tool to the desired location at the specified rate of travel. Once this was accomplished the data generated was processed through the CATIA postprocessor which converted the graphic file into a properly formatted source program needed for the ASEA "OLP" software. Through file transfer applications, the newly generated source program files were then transferred to the IBM PC for further processing through the ASEA "OLP" system.

The ASEA "OLP" is a user-friendly, menu driven, man-machine interface. Each function is invoked from the main menu by moving a cursor to highlight the desired option. There is an on-line help function which can be used whenever explanatory information about a function in question is desired.

5.6.2. Off-Line Programming Trials. Part number 3-100-400-02, Figure 5-17, was selected for off-line programming development. A 10-hole bolt pattern was identified as the first task to attempt because of its relative simplicity. Tooling was selected, measured and modeled to scale in CATIA. A robotic program was created to deburr the 10 holes and processed through the CATIA/ARLA interface. The file was transferred to the IBM PC, converted into robot machine language and downloaded to the robot's controller. Figure 5-18 (a-c) shows a graphic representation of a deburring sequence.

The first dry run indicated that initiating the deburring cycle from the robot's home position caused a singularity error, and motion was inhibited. This situation occurs when the robot's fourth and sixth

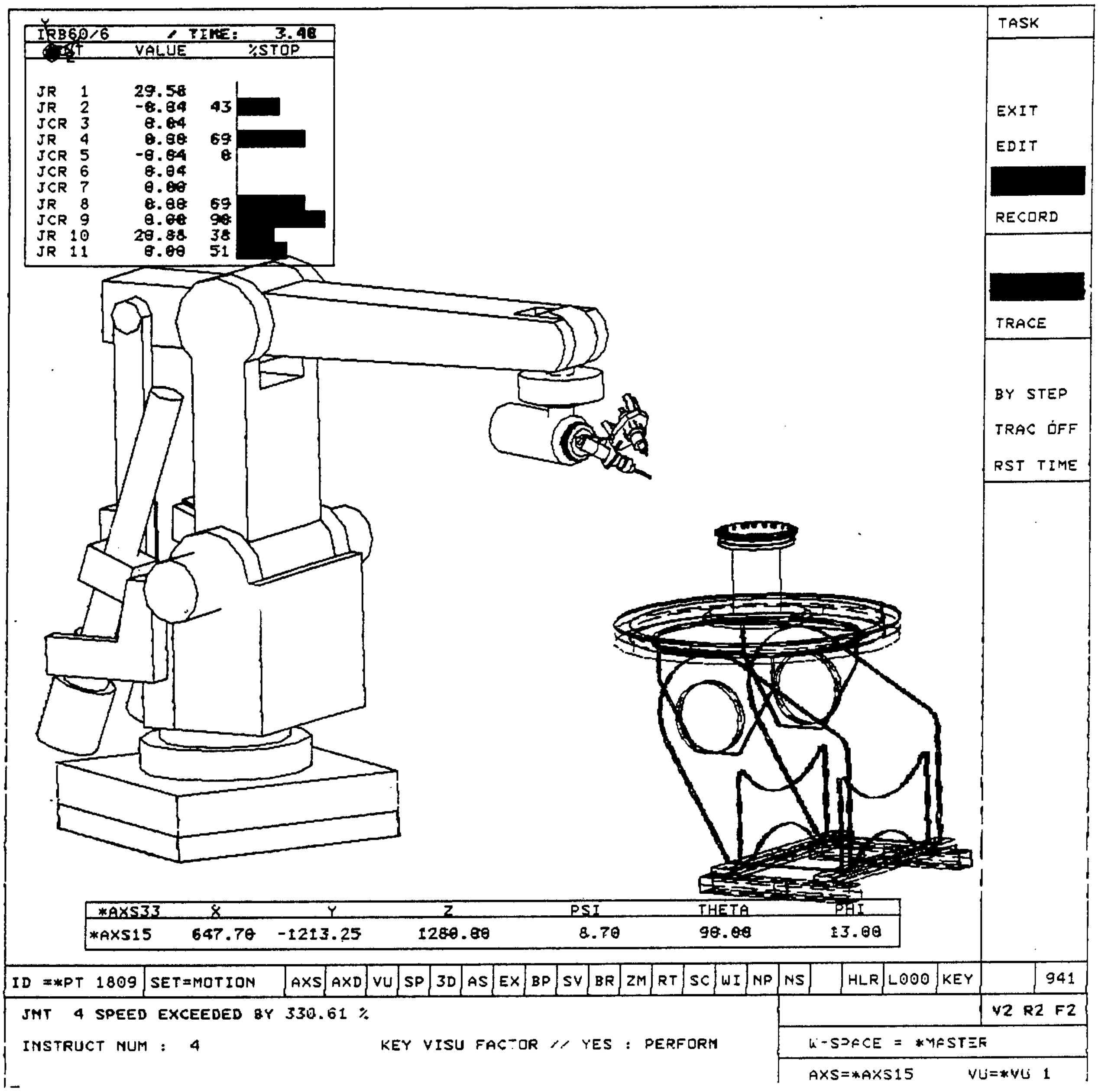


Figure 5-16. Phase I System Model

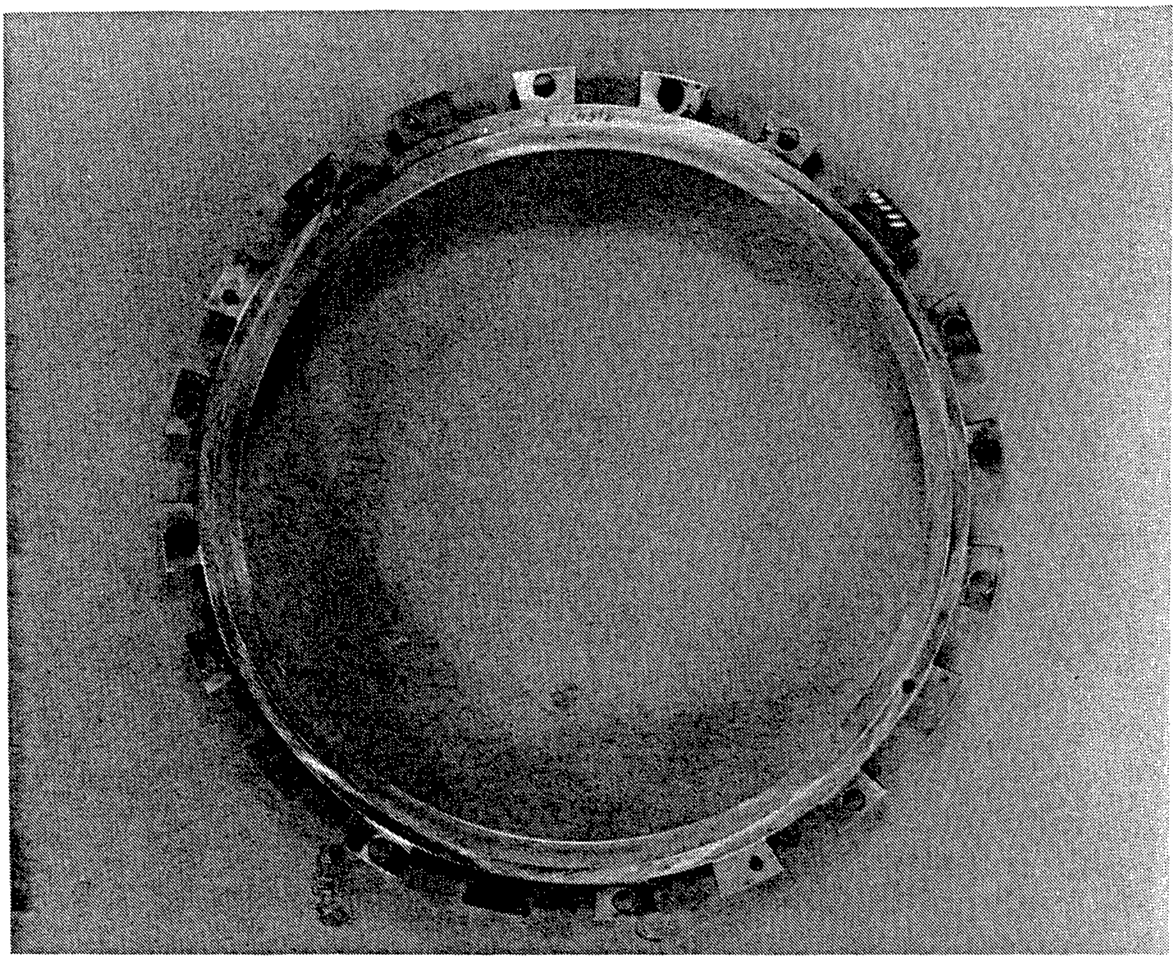
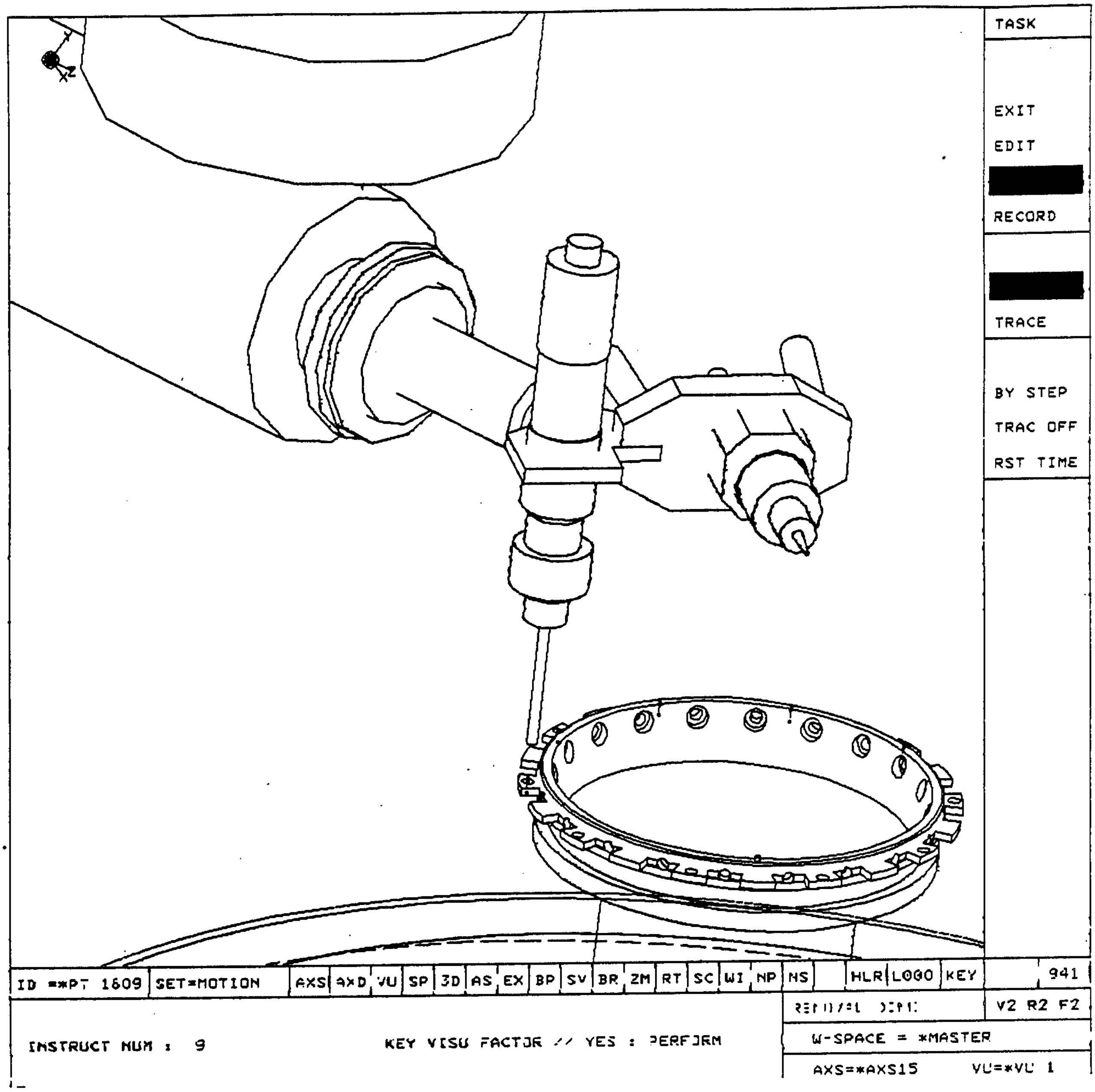
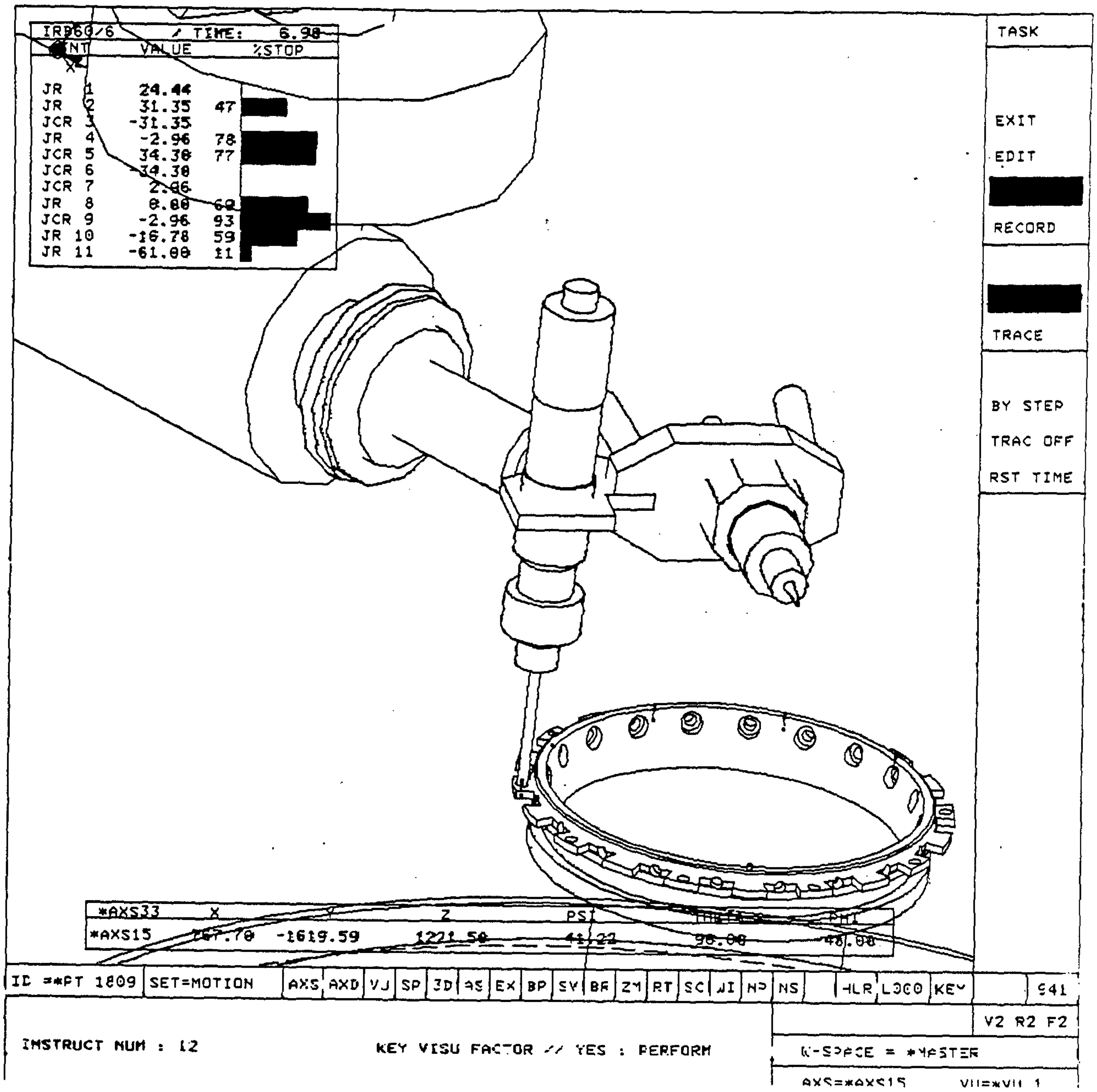


Figure 5-17. Part Used for Off-line Programming Trials



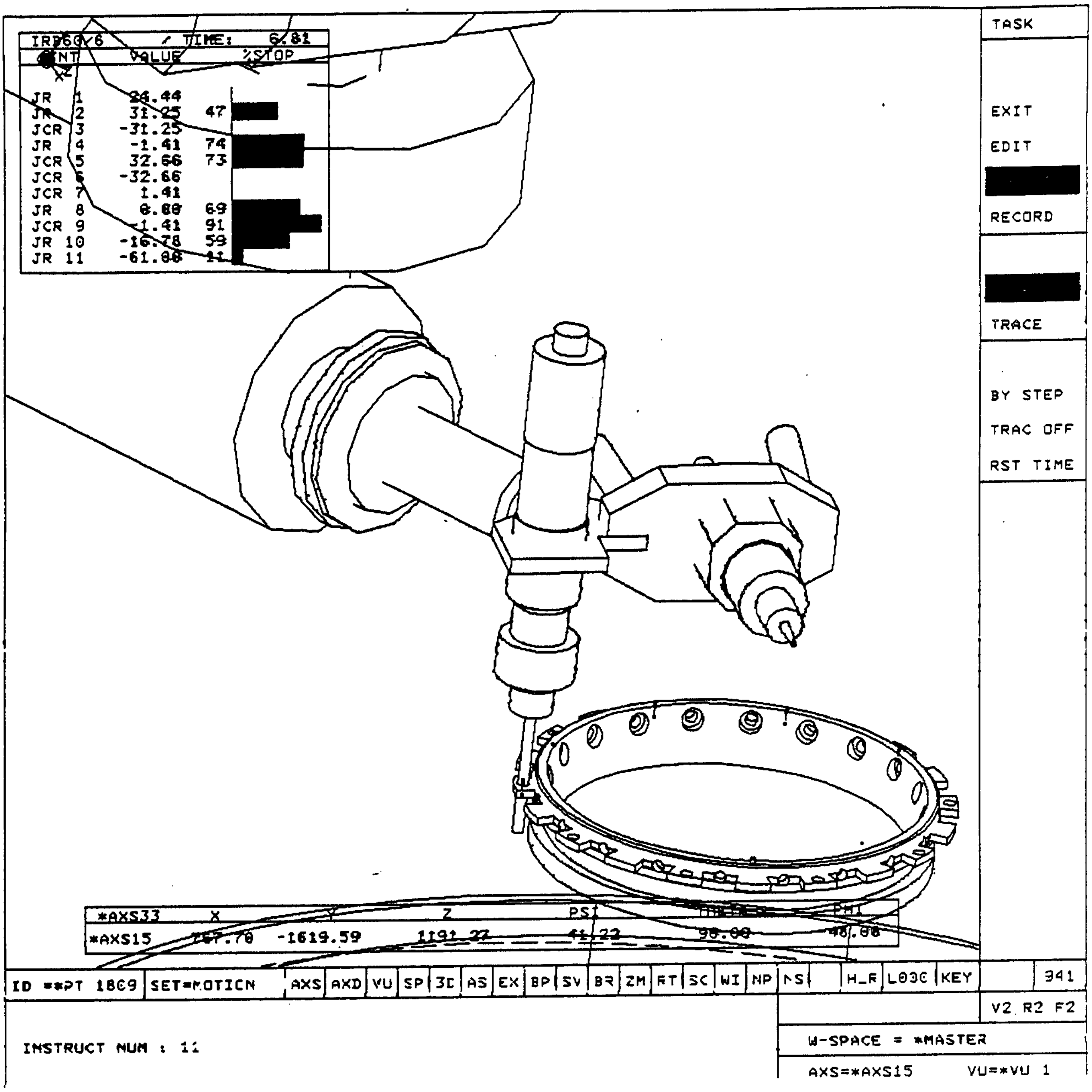
(a) Tool above hole

Figure 5-18. Sequence of Hole Deburring



(b) Tool enters hole

Figure 5-18.(continued) Sequence of Hole Deburring



(c) Tool traverses hole to deburr
upper and lower edges

Figure 5-18.(continued) Sequence of Hole Deburring

axes are parallel, which creates a condition in which the robot's controller does not know which axis to activate. ASEA was notified and they informed us that this problem is inherent in the six-axis IRB 60/2 robot, and that they were attempting to correct the problem. In order to avoid the problem, an alternate start position was established.

The next dry run proved unsuccessful in that the tool tip was not approaching the part at the specified location and orientation. Both ASEA and Dassault were contacted as to the possible cause. Various tests were made in an attempt to resolve the problem. It was determined that the problem was with the tool tip offset calculations. A meeting was held with Textron Lycoming, ASEA, and Dassault personnel in attendance. As a result of the meeting and observation of the robot's movements, ASEA determined that the Y axis sign was reversed. This was fixed and the tool then approached the work piece with correct orientation. However, it was not at the correct location. The offset distance was determined and transferred to the CATIA model. A trial program was then generated to deburr three of the first five holes on the part. This was performed successfully, and the problem was thought to be solved.

A new program was generated to perform the entire deburring operation of 10 holes using the same CATIA model as the trial task. The X, Y, and Z locations were verified to be the same as the three holes generated in the trial task.

Upon running this new program the tool once again did not position to the proper locations. ASEA was contacted and made aware of the situation. After performing further recommended testing, it was determined that the offset from the tool tip to the spindle face was inaccurate and, to compound the problem, there is no tried and true procedure to establish an accurate dimension on the six-axis IRB 60/2 robot.

5.7. Alternate Deburring Techniques

As part of the scope of work for this project, a tabulation of all AGT-1500 parts manufactured at Lycoming has been generated with associated deburring operations identified. Table 5-3 includes recommended alternate deburring methods where automatic (robotic) deburring is not practical. Operations on parts which are identified as good candidates for robotic deburring will be investigated as the production schedule permits.

5.7.1. Tumbling. This method, which has been in use for hundreds of years, involves placement of parts into a barrel filled with abrasive media, compound and water. The barrel is turned slowly, causing the abrasive media to rub on the parts. Processing times are long, and there is potential for damage to the parts as they tumble. An operator must monitor the progress of deburring action during this process.

5.7.2. Vibratory Finishing. This widely used method involves placement of parts and media into an open top container where intense vibration causes them to rub together. As with tumbling, an operator must monitor the progress of this process, which can take anywhere from minutes to 20 hours or more to complete.

5.7.3. Centrifugal Barrel Finishing. In this process, finishing drums are mounted on the periphery of a turret. As the turret spins, the parts, media, compound and water in the drums are forced to the walls of the drums. The drums are rotated slowly to create a sliding action of media against parts. The result is fast deburring since media and parts are under high centrifugal force.

5.7.4. Electrochemical Deburring. This process dissolves material from the workpiece in a manner which is the opposite of plating. Electrolyte flows between the positive workpiece and the negative electrode to remove material. The process does not produce distortion, thermal or mechanical stress, but requires custom electrode fabrication for each area to be deburred.

5.7.5. Wet Blasting. Parts are bombarded with a flow of solid particles suspended in water. The solid particles can be either abrasive or glass beads. This process can deburr, degrease and improve surface finish in one operation.

5.7.6. Thermal Energy Method. This method uses heat to deburr and deflash parts. Parts to be processed are placed in a sealed chamber which is pressurized with a mixture of combustible gas and oxygen. The mixture is ignited by a spark plug creating a burst of intense heat. The excess oxygen in the chamber combines with the burrs and forms an oxide powder. As the flame reaches the main body of the part the temperature of the burr drops below the ignition point. The oxide coating which forms over the part can be removed with a cleaning solvent.

5.7.7. Manual Deburring. This refers to conventional burr removal using hand held air motors and various deburring tools.

Table 5-3. Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
3-020-173-15	175	Gear teeth	7.8	Manual
3-020-175-24	61	Keyways, holes	10.0	Manual
3-020-175-24SF3	132	Holes, slots	10.3	Manual
	211	Teeth, spline	8.4	Manual
3-020-175-24SF5	241	Teeth, helical	4.5	Manual
3-020-410-27SF1	41	Holes	3.0	Manual
	180	Housing	10.0	Manual
3-020-470-14SF1	93	Holes	7.0	Manual
	184	Edges	15.0	Cent. Barrel
	185	Edges	20.0	Cent. Barrel
3-020-520-03	None			
3-080-075-03	152	Holes	.5	Manual
	232	Gear, spline teeth	7.7	Manual
	386	Slots, holes	2.0	Manual
	492	Gear teeth	4.0	Manual
	582	Journal area	4.0	Manual
3-080-076-01	151	Gear teeth	10.6	Manual
3-080-079-01	151	Gear teeth	17.2	Cent. Barrel
3-080-081-03	170	Spline, holes	5.0	Manual
3-080-230-03	30	Holes	1.2	Manual

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min	Alternate Method
3-080-086-01	None			
3-080-260-01	31	Holes	1.0	Manual
3-100-010-08	125	Edges	14.2	Manual
3-100-020-12	122	Edges	14.2	Manual
3-100-030-10	124	Edges	15.1	Manual
3-100-145-07	212	Slots	3.6	Manual
	329	Spline	7.6	Manual
	383	Slots	15.0	Manual
3-100-440-08	122	Edges	15.0	Manual
3-105-011-21	240	Spline	6.9	Manual
	440	Edges	1.5	Manual
	590	Gear teeth	5.0	Manual
3-105-040-09	121	Edges	6.0	Manual
3-105-050-09	121	Edges	16.5	Manual
3-105-052-05	215	Gear teeth	5.6	Manual
	473	Gear teeth	5.0	Manual
3-105-060-06	122	Edges	16.5	Manual
3-105-070-07	124	Edges	4.4	Manual
3-105-200-11	70	Blade edges	6.3	Manual
3-105-210-04	30	Blade tip edges	6.3	Manual
3-105-230-11	150	Edges imp. vanes	20.0	Manual

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
	251	Edges imp. vanes	20.0	Manual
3-105-240-14	60	Edges	25.0	Robotic
3-110-002-65	100	Blade edges	1.2	Manual
	130	Blade edges	.6	Manual
	140	Blade edges	.2	Manual
3-110-002-65SF1	None			
3-110-008-11	220	Holes	5.0	Manual
	240	Holes	5.0	Manual
	270	Deburr	6.0	Manual
3-110-058-07	None			
3-110-140-31	None			
3-110-140-31SA1	None			
3-110-170-08	None			
3-110-014-07	30	Edges	1.0	Manual
	132	Edges	.6	Manual
3-110-122-01	None			
3-110-380-05	160	Deburr	2.0	Manual
	252	Trim edge	2.6	Manual
3-130-020-15	None			
3-130-030-54	67	Deburr	2.0	Manual
3-130-153-04SF1	40	Edges	1.5	Manual

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
	7140	Keyhole slots	1.1	Manual
3-130-205-03SF1	43	Weld	4.0	Manual
3-130-205-01SF1	44	Weld	1.2	Manual
	61	Weld	1.2	Manual
3-130-700-13SF1	23	Holes	8.0	Manual
3-130-045-07	30	Edges	3.5	Manual
3-130-003-12	40	Edges	.6	Manual
	71	Deburr	2.2	Manual
	122	Shroud I.D.	.9	Manual
3-130-006-11	40	Deburr	.6	Manual
	71	Deburr	2.2	Manual
	111	Deburr	.9	Manual
3-130-060-13	180	Deburr	13.5	Wet Blasting
3-130-070-14	103	Deburr	5.0	Manual
	121	Holes	1.0	Manual
	190	Holes	10.0	Manual
	270	Holes	2.5	Manual
3-130-090-26	None			
3-130-224-08	40	Edge break	1.3	Manual
	90	Edge break	1.5	Manual
	140	Holes	10.0	Manual

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
3-130-130-18	152	Hole	1.0	Manual
	182	Holes	2.0	Manual
3-130-750-19	60	Deburr	11.0	Cent. Barrel
	216	Edge break	5.0	Cent. Barrel
	260	Deburr	5.0	Cent. Barrel
3-140-045-09	234	Deburr	8.9	Manual
	383	Deburr	15.0	Manual
3-140-047-08	354	Deburr	25.0	Manual
3-140-080-12	51	Edges	2.0	Manual
3-140-114-12	61	Deburr	.5	Manual
	112	Holes	8.7	Manual
3-140-353-01	None			
3-140-800-07	240	Edges	5.0	Manual
3-140-094-16	80	Edges	2.0	Manual
	110	Holes	6.0	Manual
	150	Holes	2.0	Manual
3-140-094-16SF1	None			
3-140-194-13	180	Deburr	15.0	Cent. Barrel
3-140-202-33	150	Deburr	15.0	Cent. Barrel
	300	Slots	6.0	Cent. Barrel
	490	Edge Break	13.0	Cent. Barrel

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
3-140-202-33SF1	140	Deburr	15.0	Cent. Barrel
	290	Slots	6.0	Cent. Barrel
	480	Edge break	13.0	Cent. Barrel
3-140-218-04	51	Deburr	5.0	Manual
	110	Deburr	5.0	Manual
3-140-430-06	None			
3-140-490-R11	182	Deburr	9.5	Manual
3-140-046-05	30	Edge	15.0	Manual
3-140-500-R09	142	Deburr	9.5	Manual
3-140-660-13	08	I.D.	5.0	Robotic
	330	Holes and slot	10.0	Robotic
	360	Edge break	44.0	Robotic
3-500-010-41SA1	None			
3-500-031-12	None			
3-500-031x11	None			
3-500-032-08	None			
3-500-070-07	None			
3-500-221-05	37	Deburr	5.0	Manual
3-500-222-02	90	I.D., O.D., holes	3.6	Manual
3-500-239-07SF1	30	Edge break	3.0	Manual
	60	Edge break	3.0	Manual

Table 5-3. (continued) Alternate Deburring Methods for AGT-1500 Parts

Part Number	Op.No.	Op.Descrip.	Std.Min.	Alternate Method
3-500-277x01	41	Edge break	2.9	Manual
3-500-296-01	None			
3-500-480-17	None			
3-500-480-17SA4	None			
3-500-510-05	None			
3-500-520-07	None			
3-500-520-07SF1	None			
3-500-650-13	162	Fwd & Aft ends	32.0	Robotic
3-140-870-04	None			
3-500-710-07	None			

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